similar period. Another feature that is interesting is that most bituminous roads become better under maintenance. Further, a large number of people can be satisfactorily served with a fixed yearly revenue by using, where practical, some of the light bituminous surfaces.

DESIGN FEATURES OF CITY PAVEMENTS

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By request, this paper is confined to a discussion of design features in concrete pavements for city use. It is obvious that design features of pavements, as of any engineering structure, vary with the use. Treatment of this subject logically will deal with a number of broad general situations affecting that use. Design features will vary according to the location of the improvements, whether in an area that is devoted to residential or business purposes. The design will be influenced by existing conditions, i. e., if in an area fully, or nearly completely occupied by residences or business houses, or in an area untouched by previous improvements and wholly undeveloped.

Design of Profiles

When a pavement is laid in an area in which building grades of existing structures wholly determine the design of profile, the engineer has little opportunity of producing grades that serve any greater purpose than simple utility. His opportunity of designing a profile that is pleasing to the eye of the observer is limited and circumscribed in many cases by the existing building grades which have come into existence at random without any conscious effort at planning. The result, as it relates to the appearance of the profile, is often anything but pleasing.

When designing profiles in an area unhampered by existing structures, as in a new subdivision, the engineer should by all means exercise his artistic sense in order to produce a pavement profile that does not destroy the natural features of the property and landscape. In areas of irregular and rolling topography, particularly in residential areas, paving profiles should follow the topography of the land, preserving, in so far as it is possible, those natural features which are prized by every prospective purchaser as a natural asset. Sharp vertical deflections in the grade lines should without exception be avoided. Vertical curves should be employed at every point of change in such a manner as to blend completely the pavement lines and the general topography. It is not important that vertical curves should be mathematically designed. It is usually impossible to apply the mathematically accurate curve to the many situations that occur in the design of a pleasing profile. Freedom from mathematical severity is in fact desirable. The profile should further be designed to afford not only sufficient earth cut to complete the necessary earth fills in the street proper, but should take into careful consideration the needs of each foot of abutting frontage in order not to sacrifice lot value to excessive cuts and fills.

Selection of Width

The selection of width of pavements is entirely a matter of safe and practical use, as fixed and determined by the character and volume of traffic. For residential areas, there has been quite universally adopted a rule of providing sufficient width to permit the parking of vehicles on both sides along the curb, with sufficient space to permit the safe passage of one line of traffic. This idea requires a width of not less than 26 feet, allowing 8 feet of parking width and 10 feet for traffic lane. Experience, observation and practical demonstration have, in the past 15 years, resulted in the adoption of these widths as practical and safe. For business streets, the minimum width should be 36 feet, allowing sufficient space in addition to two parking strips for two ten-foot traffic lanes. This plan, of course, presumes that parking will be done parallel to curb lines. If it is desired to adopt the diagonal head-in parking plan, a minimum of 15 feet parking space should be provided for on each side of the street, making a total width of pavement of not less than 50 feet, preferably 54 feet.

Pavement widths will vary by multiples of 10 feet widths, according to the number of traffic lanes necessary to take care of the traffic safely and readily. It is, of course, obvious that the traffic lanes should be provided in pairs to meet the needs of traffic with the maximum degree of safety. It is not impractical, however, to use an odd number of traffic lanes, where it proves to be economical on a basis of first cost, and in situations where it is practical to regulate traffic on the odd lane as may be required.

Arterial highways through cities should, by all means, have a width of 36 feet with a recommended width of 40 feet to provide greater safety for the greater speed that may be expected in the traffic lanes. Where car tracks are to be provided for, sufficient clearance along the side of the track should be provided to enable the passing of the moving traffic and the parking of cars on each side of the car tracks, which requires a minimum of 19½ feet from the gauge line to the curb face.

Design of Cross Sections

The cross sectional form and dimension of the pavement slab depends upon three major considerations; first, the loads to be transported over the slab surface; second, the strength of the materials entering into the construction of the slab; and third, the character and stability of the subgrade support of the slab.

For purposes of design of slab thickness, the maximum legal load, usually 4 to 5 tons per rear wheel, is used. There have been a number of formulas developed for the purpose of determining slab thickness, concerning which it is the express purpose of this paper to avoid particular discussion. A very simple formula, however, developed as a result of the Bates Road Test of Illinois, is as follows: Edge thickness should equal the square root of three times the wheel load divided by the allowable stress in the concrete per square inch. Allowable stress is usually taken as one-half the modulus of rupture, or approximately three hundred pounds per square inch for 1-2-3½ concrete. Any formula attempting to introduce complex influencing factors is in the estimation of the writer of little value, as at best only roughly approximate influences are discernible and determinable in the application of a practical formula. The usual thickness adopted ranges from 6 inches to 10 inches as indicated by the needs of the practical highway. The durability of the slab, under practical use and under various conditions of grade and climate, has been carefully observed and has afforded the engineer the sole guide for continued investigation and change of design. Actual experiments have shown the weakness of the slab in place. The development of cracks in the slab indicate these points of weakness. The casual observer has certainly noticed in our miles of concrete highway the development of the center line crack which engineers have since quite successfully confined by the adoption of a center line joint. Failure of the edge of the slab, as indicated by peculiar cracks, has shown that the edge is in fact the weakest point of the pavement slab; and to offset this naturally manifest weakness, engineers have adopted quite generally the theory and practice of thickening the edge of the slab for a distance of 1½ to 2 feet toward the center line joint of the pavement, in accordance with the formula mentioned. Thickness of the slab at the center equals the square root of one half of three times the wheel load, divided by the allowable stress in the concrete.

The life of any slab in most cases is no greater than the stability of the subgrade bed upon which it rests. A discussion of soil mechanics as it relates to highway subgrade might be introduced at this point at great length, but will be avoided with the simple but very important observation that the subgrade should in every instance be firm, and of uniform density as well as of uniform structural nature, if the best results are to be obtained from the slab. The unnatural compaction of sub-grade, as formerly quite prevalently required, is detrimental rather than of value since it is impossible to maintain any soil in an unnatural degree of density for an indefinite time. For that reason the use of heavy rollers is not important. In case of extremely deep fills trouble will inevitably develop by reason of settlement of the slab unless a period of subsidation through at least one winter and a wet season is allowed for the soil fill to acquire its natural density and final repose.

Much thought and effort have been given by engineers to the development of a crown formula in the design of pavements, which is in fact of little importance as it relates to a concrete slab. There is but one consideration of importance, namely, that the slab surface be inclined sufficiently to drain. In northern climates where snow and ice are likely to incrust the slab, surface slope is of very considerable importance in preventing these accumulations and facilitating drainage during thaw. A concrete slab with no crown whatever should be acceptable from engineering standpoint under mild climatic conditions.

Reinforcements

The use of steel reinforcement in the slab was introduced probably in the first instance to augment the strength of the slab. There is some additional strength to be derived in this way. It is, however, quite well recognized that steel reinforcement in the form of meshed fabric of relatively small caliber wire, rather than heavier bars, placed in the upper portion of the slab, serves the more important purpose of preventing the development of surface cracks as well as of holding together the portions of the slab which may have developed rather noticeable cracks. The use of reinforcing in the lower stratum of the slab for the purpose of strengthening the slab presupposes a faulty subgrade, which should not in any instance be permitted to exist.

Joints

In addition to the adoption of the center line joint, engineers quite generally have recognized the destructive effect of expansion and contraction in the slab due to change in temperature and moisture content. Actual tests scientifically executed have shown the amount of contraction per foot of length per degree Fahrenheit, in the usual mixture of concrete, to be approximately 0.0000055 of a foot, or an approximate figure about one inch per 100 feet of slab. As a general rule, therefore, a provision of not less than one inch of expansion joint space should be allowed per 100 feet of pavement. It has been observed that the length of slab between expansion joints suffers internal stress due to temperature changes, resulting in transverse cracks at points intermediate between 100 foot expansion joints. It is, therefore, advisable to provide contraction joints not less than one and usually two, as may be dictated by conditions of the job for each 100 feet of slab.

Design of Intersections

Intersections of pavements should be designed as spaciously as possible in order to insure the greatest safety to traffic. Profile grades across intersections should be continuous as nearly as possible to effect the best riding qualities. In case of grades exceeding four per cent, it becomes necessary in the interests of safety of the moving vehicle to design the approach slopes of the intersection with great care. The judicious use of properly warped grades will remove much of the hazard to moving vehicles and will at the same time produce a pleasing effect to the eye. The building-up of the intersection crown above the general crown profile of the intersecting streets should be avoided. The curb returns of intersecting streets should have a radius of not less than 25 feet in order to permit the natural and easy trailing of the rear wheel around the corner. The unusual intersection, resulting from the approach of several streets at odd angles, presents a problem in each case that is not conformable to a uniform set of rules, except in the general sense that has been stated.

Design of Curbs

Concrete curbs are constructed in three usual forms, each of which is quite common. The integral curb is constructed monolithically with the pavement slab. This, while presenting some difficulties in constructing, is very desirable because of its function in strengthening the pavement slab in the same manner as a thickened edge. The second form of curb, usually described as the combined curb and gutter, is quite prevalently used in residential areas, being constructed in 5 or 6 foot lengths, previous to the construction of the paving slab. It has been a rather popular form among constructors for the reason that it provides a convenient border for the slab during construction. Recent development, however, in the use of finishing machines on the city pavements have made it quite practical and preferable to construct the curbs subsequent to the pavement slab. The practice of tying the curb and gutter to the slab with steel tie bars has become recognized as a sound and useful one, overcoming the common tendency of the curb block to sag and settle from the paving slab. A third form of curb is the retaining wall type, cast in place but functioning in the same manner as the stone slab curb. This form of curb is particularly desirable in business areas. There have been designed, also, flat types of curb, in which the gutter and curb surface are blended to form a less severe curb line. This type of curb is useful only in park areas or in residential areas, and is recommended only for its appearance.

Design of Drainage

Storm waters from city pavements should be taken off at as frequent intervals as practically possible. In business areas the run should not exceed 300 feet for pavements of ordinary width. In residential areas the interval may be much greater since the concentration of storm flow is not nearly so rapid. It is usually practical to take off storm waters at street intersection points by means of cast iron grates placed in the gutter line superimposed upon a catch basin of suitable design. The precise form of the casting will be selected in accordance with the type of curb used, care being exercised that the available grate opening area through the casting is sufficient to permit the entrance of the maximum storm flow into the basin with an additional margin of capacity to off-set the effect of obstruction carried by the flowing water, such as leaves and debris. In residential areas where there are numerous trees, the latter precaution is very important. Various types of drainage castings are available without the necessity of special design.

The pipe lines from basins to the main drain or sewer should not be less than 10 inches in diameter, preferably 12 inches, and should be laid as directly as possible.

Location of Subsurface Structure

The proper location and disposition of pipe lines, such as water mains, gas mains, sewers, heat tunnels, and conduits, in city streets is a matter of great concern and in large cities particularly tax the ingenuity of engineers to the limit. Their disposition under the pavement prior to its construction should be precisely mapped and recorded in order to avoid unnecessary destruction of the paving slab when emergency requires the exposure of any portion of these subsurface structures. In new residential areas, there has been a definite tendency on the part of engineers to remove all pipe lines from streets into easements at the rear of lots, in order to avoid an inevitable damage to the subgrade entailed in their construction, and the subsequent injury to the pavement due to emergency cuts. The suggestion also has been made of laying duplicate parallel lines of water mains and other service lines on each side of the pavement rather than beneath them, in order to avoid the construction of service lines from the main to each residential lot. This scheme, though in use only in rare instances, can be shown to be economically practical in streets having a platted width of more than 40 feet.

Design of Walks and Park Strips

The concrete walks in business areas, by custom and requirements, should cover completely the area between the curb and the property line. In residential areas the sidewalk should be constructed parallel to the property line, approximately one foot distant, and should have a minimum width of 3 feet, for areas in which lot frontages exceed 100 feet, and a minimum width of 5 feet in all subdivisions of the usual 40 to 50 feet frontages. The sidewalk should be not less than 4 inches in thickness and should be laid at a grade usually parallel to and above the curb grade so as to permit the grade of the park strip at a slope of not less than one-half inch to one foot in width. The use of special surface finishes and color in sidewalk surfaces is becoming popular in many places and has a definite artistic appeal when carefully done.

Materials and Specifications

The most careful, painstaking design on the part of the engineer may be rendered less than useless if the materials entering into the construction of concrete are inadequate in quality and quantity. In the construction of concrete work, very rigid supervision and inspection during its progress should be exercised, every detail consistently and thoroughly enforced.

Inspection and inspectors must be intelligent. The all too common practice in public work of employing ignorant irresponsibles at usually small salaries for the purpose of guiding and approving important details of construction, is a matter of keen regret to every conscientious engineer. Supervisor and inspector should be men of dependable integrity, judgment, and general intelligence. Such men must be adequately paid. They must be trained to their duties, thoroughly informed as to the details of the job, and possessed of a personality that invites and obtains the co-operation of the contractor and the workmen. He should be employed by and be directly responsible to the engineer, as a part of the engineering staff, so that the entire responsibility for the quality of the work will rest on the engineer. If, under such a set-up, failures and inferior results are obtained, there will be no opportunity of evading the issue and "passing the buck". Engineers as a rule will welcome responsibility if commensurate authority and control is accorded thereto.

Specifications should by all means set out minimum strength requirements imposed under definite standards. The making of tests for quality and quantity should be carried on consistently through the job at regular intervals. Molded cylinders, core cylinders, test beams, cement tests, tests for cleanliness and gradation of aggregates, and slump tests, all have been developed to a fine nicety and should be employed religiously by the engineer if excellence and near perfection are to be attained. The cost of good and sufficient inspection is low, in the light of the guaranties assured and the benefits derived.

The writer takes pleasure in recommending to any person interested in obtaining concise and dependable information on "The Design and Construction of Concrete Pavements," the booklet published by the Portland Cement Association under that title. It will be found to set forth briefly and completely, and in a practical and sensible manner, all of the information that is required to design a concrete pavement in a fundamentally correct way.

SCIENTIFIC CONTROL OF STREET PAVING MATERIAL

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I shall not attempt at this time to outline or discuss in any way the merits of the various methods of scientifically controlling paving materials. Whether the materials are controlled by weight, volume, specified modulus of rupture or compressive strength, or otherwise, depends upon the engineer and the locality where the construction is proposed. It is my intention merely to try to prove the important fact that scientific control of paving materials in some way is the only guarantee to the engineer that he has determined by a practical method some definite fair value of this paving product, in comparison to its cost. Merely to specify the mix determines no fair value in relation to its cost. This subject, as outlined, would therefore be better understood if titled "Practical Control of the Street Paving Dollar."

Very few cities have attempted scientifically to control paving materials in any way. The application of such control in its fullest extent to street and alley construction presents problems unlike those encountered in county and state highway construction. Its application in the cities in some cases demands a drastic change in the paving industry, as well as changes in the relation of the engineer to the contractor. Indianapolis specifies a minimum strength of concrete, requiring 2000 lbs. per square inch compressive strength for foundation pavements and 3500 lbs. per square inch compressive strength for standard concrete pavements before acceptance. By this method we are attempting to control scientifically the paving materials in a practical way. This specification has been in force for the last three years.

In determining a definite quality of concrete, a certain value naturally is placed thereon, which in my estimation is eliminat-